EXHIBIT 13

CAP-101/PROV

3-21-01

A PROV

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JC490 U.S. PTO 09/810701 03/16/01

JC973 U.S. PTO 60/277217 03/19/01

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ET 050627124 US

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Jeffrey P.	Wilde	Los Gatos, CA

☐ *Additional inventors are being named on the ___ separately numbered sheets attached hereto*

TITLE OF THE INVENTION (280 characters max)

Reconfigurable Optical Add-Drop Multiplexer with Dynamic Spectral Equalization Capability for DWDM Optical Networking Applications

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number [ ] → *Place Customer Number Bar Code Label here*

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ENCLOSED APPLICATION PARTS *(check all that apply)*

[X] Specification *Number of Pages* 18

[X] Drawing(s) *Number of Sheets* 22

☐ Application Data Sheet. See 37 CFR 1.76

☐ CD(s), Number

☐ Other (specify)

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Respectfully submitted,

SIGNATURE Jeffrey P. Wilde

Date 3/17/01

TYPED or PRINTED NAME Jeffrey P. Wilde

REGISTRATION NO. *(if appropriate)*

Docket Number:

TELEPHONE (408) 360-4243

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

PROVISIONAL PATENT APPLICATION OF

JEFFREY P. WILDE

for

RECONFIGURABLE OPTICAL ADD-DROP MULTIPLEXER WITH DYNAMIC SPECTRAL EQUALIZER CAPABILITY FOR DWDM OPTICAL NETWORKING APPLICATIONS

FIELD OF THE INVENTION

This invention relates generally to optical communication hardware, and more specifically to hardware designed for use in dense wavelength division multiplexed (DWDM) systems. The invention describes a new device design for providing two important functions of importance in emerging DWDM systems: (1) reconfigurable add-drop of individual wavelength channels, and (2) spectral equalization of wavelength channels.

SUMMARY & DETAILED DESCRIPTION

The more detailed disclosure of the present invention is contained in the following description and figures, as supplied by the attached appendices.

Appendix A: Design Concept for DWDM Multi-Channel Dynamic Add/Drop Module, by J. P. Wilde, 7/28/00
Appendix B: Modified Dynamic OADM Design, by J. P. Wilde, 11/28/00
Appendix C: Reconfigurable OADM with Dynamic Equalization, by J. P. Wilde, 12/28/00
Appendix D: Technical Specifications 1/9/2001, Dynamic Optical Add/Drop Multiplexer

Overview and Objective

Emerging DWDM communication systems are in need of a robust and low-cost device technology for providing dynamic optical add-drop of wavelength channels at node sites as shown in Figures 1 and 2. Such a device -- referred to as an optical add-drop multiplexer (OADM) -- should by remotely reconfigurable through software control. It is desirable to have complete control at the granularity of a single wavelength, meaning any individual wavelength channel can be added/dropped by the device.

Long-haul and ultra-long-haul applications require the OADM to support a large channel count (80 channels today, heading to 160 channels or more in the future). Therefore, a technology that is intrinsically scalable to such channel counts is needed. Moreover, it is important that the optical loss introduced by the device be independent (or only weakly dependent) on the number of channels. The device should also have low polarization

dependent loss (PDL) and low polarization mode dispersion (PMD). A general set of device specifications is outlined in Appendix D.

Figures 3 and 4 illustrate two basic approaches, parallel and serial, to constructing a dynamic OADM. The parallel architecture is intrinsically scalable to large channel counts, and is the general approach taken in this invention. The serial scheme has various limitations as noted in Figure 4.

A parallel architecture based on free-space optics has been previously described in Ref. 1. A block diagram of this device is shown in Figure 5. It has four fiber ports: (1) input, (2) pass-through, (3) add, and (4) drop. One circulator is used to combine the input and pass-through ports onto one fiber, and another circulator combines the add and drop ports to a second fiber. Figure 6 shows a graphic of the optical system configuration of the OADM device described in Ref. 1. Two coupling lenses are implemented to convert the light paths from these two fibers to free space. Wavelength separation and routing are done in free space. The device utilizes a ruled diffraction grating to separate the input light into its constituent channels. A binary micromachined mirror array redirects each of the individual channels to one of two outputs. Each mirror in the linear array either retroreflects its corresponding channel back along the original input path towards the pass-through port, or it reflects its channel to the drop port.

While this architecture is attractive in the sense that it is compact and scalable to high channel count, it also has a number of limitations. First, the design requires precise alignment of components that makes assembly during fabrication complex and expensive. Second, no provisions are provided for maintaining the relative alignment of the optical components so that the system performance may degrade over time, or in the presence of shock and vibrations, or due to a temperature change. Third, it requires all the add and drop wavelengths to enter and leave the device on single fibers. In other words, additional means must be provided to multiplex the add channels onto a single fiber and to demultiplex the drop channels from the single fiber output from the device. This additional mux/demux requirement can lead to significant additional expense.

What is needed is an improved free-space architecture that overcomes these limitations.

Description of the Invention

The OADM device architecture disclosed here has all the positive attributes of a compact, parallel design, and also overcomes existing limitations by providing (1) a more versatile architecture with multiple physical add and drop ports, (2) analog mirrors under servo control that loosen fabrication tolerances and provide self-alignment to correct for component drift during operation, (3) additional optics to provide the servo feedback signal, and (4) a servo system scheme that provides for dynamic spectral equalization on a channel-by-channel basis.

OADM Architectures

Three different OADM architectures disclosed in the present invention are shown in Figures 7-9. All of these architectures provide for dynamic drop of one or more wavelength channels on any one of multiple drop ports. The "wavelength separation and routing" (WSR) function is common to all three architectures and is performed using free-space optics and silicon micromirrors. The optical loss of the WSR unit can be fairly low, its value being determined by the diffraction efficiency of a grating or similar dispersive device used for wavelength separation. A typical value is in the range from 2 - 4 dB. For the preferred case in which only one wavelength is dropped on each drop port, then no additional wavelength demultiplexing is required before the signals carried by the respective channels are received by photodetectors. The three approaches of Figs. 7-9 differ primarily in the way in which the add function is implemented.

The first of these (Fig. 7) is designed for one-way optical propagation. It uses a combiner (or 1xN coupler; e.g., the 1x16 broadband coupler sold by Newport Corp., Irvine, CA, product model number F-CPL-B16350) for injecting the add channels into the pass-through port. While use of a combiner is straightforward, the associated optical loss can be large (e.g., the 1x16 Newport coupler may have up to 14.5 dB of loss). For those situations where the loss can be tolerated, this is suitable approach.

The second architecture (Fig. 8) is designed for bi-directional operation and has better loss performance compared to the first embodiment. Two WSR units are utilized, with one unit providing dynamic drop and the other dynamic add. This architecture is very general, with no fundamental restrictions on the wavelengths that can be added or dropped (other than those restrictions imposed by the overall communication system).

The third architecture (Fig. 9) is also bi-directional, but uses only one WSR unit. Circulators are situated on all of the physical input/output ports, allowing for two-way optical propagation. This design has the restriction that at each of the add/drop ports, the add and drop wavelengths must be the same.

Free-Space Optical Embodiments

One embodiment of the present invention is shown in Figure 10. The input/output consists of a linear array of fiber collimators. Such collimators are well known in the art and are comprised of a collimating lens and ferrule-mounted fiber packaged together in a mechanically rigid stainless steel or glass tube (e.g., see collimators made by ADC Photonics, Inc., Minneapolis, MN, www.adc.com). The collimators can be positioned in a linear array by, for example, means of a V-groove array made out of any of a variety of materials including silicon, plastic, or ceramic. The top collimator is designated the input, the second collimator is designated the pass-through, and the remaining collimators are designated as drop ports.

Multi-wavelength light from the input collimator is directed to a ruled diffraction grating. The grating separates the different wavelength channels into different diffraction angles.

In the preferred embodiment, -1 order diffraction is assumed. A focusing lens receives the diffracted light and focuses it onto a linear micromirror array positioned in the back focal plane. The lens has the property that it brings the different wavelength channels to focus at separate spatial locations such that each channel is associated with a unique focused spot. Each wavelength channel is associated with a single mirror in the micromirror array. Figure 10 illustrates only three wavelengths for simplicity. Figure 11 shows a close-up view of the micromirror array, with each of the three wavelengths falling on its respective mirror.

Each of the mirrors in the micromirror array reflects its associated wavelength channel back through the focusing lens, to the grating, and back towards one of output ports. This requires the micromirrors to be dynamically adjustable with at least one axis of rotation. The rotational motion should be under analog control, so that the angles can be continuous adjusted to scan across all possible output collimator ports. Various types of micromachined mirrors and deflectors exist in the art. One prior art implementation is shown here in Figure 12. This is an array of reflective ribbons, the position of each ribbon being under electrostatic control (made by Silicon Light Machines, Inc., Sunnyvale, CA). An adaptation of such a ribbon array can be used in the present invention to provide the micromirror function, with each ribbon in the array acting as a separately controllable mirror.

In the preferred embodiment, the grating is placed in the front focal plane of the focusing lens, thereby producing a telecentric optical system. A telecentric system has the property that the chief rays of the focused beams are all parallel to each other and generally parallel to the optical axis. In this application, the telecentric design allows the reflected beams to efficiently couple back into the output collimators, with little translational walk-off error (perpendicular to the vertical collimator array plane). A quarter wave plate is placed in front of the focusing lens to provide the desired polarization properties as discussed in Ref. 1 (namely minimal PDL and PMD).

By controlling independently the angle of each micromirror, the system has the ability to direct each wavelength channel to any of the outputs (pass-through or drop). The presence of multiple drops ports allows for the possibility of putting only one wavelength on one drop port, thereby avoiding the additional demultiplexing (and the associated cost and complexity) that would otherwise be required with the prior art device of Figures 5 and 6. Feedback control of the mirror positions makes the system stable. More detail regarding the control system is provided in the following sections. This system can readily scale to large channel count by simply adding more mirrors to the mirror array.

The results of an optical ray trace model are shown in Figures 13-15. The collimated beam diameter is approximately 1 mm. The angle of incidence on the grating is 85 degrees, and the grating spatial frequency is 700 lines/mm. The grating is blazed to optimize the –1 order diffraction efficiency. An f=30 mm ideal focusing lens captures the diffracted light and focuses it to the micromirror plane (denoted as the spatial light modulator (SLM) plane in Figures 13-15). In this model, the grating is not placed in the front focal plane of the focusing lens, so this configuration does not represent the

preferred telecentric embodiment. However, this non-telecentric system is useful for illustrating some of the spatial scales of a typical embodiment. For example, wavelength channels separated by 100 GHz (0.8 nm) are focused in the SLM plane with a 17-micron pitch. The shape and size of a focused wavelength channel, along with the relative spacing between two adjacent channels, is shown in Figure 15. It is seen that adjacent channels are separate and resolvable. The side view of Figure 14 shows that mirror deflection of approximately 1.15 degrees is needed to direct a beam between adjacent output collimator ports, with the ports lying on a 1.2 mm pitch.

Additional Actuation for more Robust Servo Control

The action of the mirrors in the micromirror array serves to translate the various wavelength beams to their respective output collimator ports. However, to provide more control over the coupling efficiency back into a collimator, additional degrees of freedom are needed. In particular, it is advantageous to have control over the two incoming angles (θx and θy) into the collimator. One method for achieving such control is illustrated in Figure 16. Here a collimated beam reflects off of a dynamic mirror capable of rotation about two orthogonal axes. A 4-f telecentric optical system images the mirror onto the front focal plane of a coupling lens, in this case the entrance surface of a quarter-pitch GRIN lens.

The sensitivity to change in the mirror angle depends on the focal length of the coupling lens. For the GRIN lens used in Figure 16, the coupling efficiency versus mirror deflection plot shows that a change of a few tenths of one degree is sufficient to go from optimum coupling to near zero. The 2-axis dynamic mirror can take the form of a double-gimbaled torsional mirror. A single-axis torsional mirror is described in Ref. 2, while a two-axis version of such a torsional mirror is described in Ref. 3, and a version developed by Lucent Technologies is shown in Figure 17.

Accordingly, additional embodiments of the present invention are shown in Figures 18 and 19. In Fig. 18 a 1xN dynamic mirror array is added, along with two 1xN lens arrays to comprise a telecentric system capable of controlling the angle of the return beams into all of the output collimators. Moreover, the top dynamic mirror in the 1xN array allows the angle of incidence of the input beam onto the grating to be controlled. In this way the spot array can be actively aligned to the micromirror array in the back focal plane of the focusing lens. Extending the input/output plane to two dimensions as shown in Figure 19 can increase the number of output collimator ports. In this case each mirror in the micromirror array must be capable of providing two axes of deflection. Additionally, a 2-D dynamic mirror array, along with two 2-D lens arrays for telecentric imaging, provides control of the angular input into the collimators.

Dynamic Spectral Equalization

The use of micromirrors with analog deflection allows the coupling efficiency to be controlled on a channel-by-channel basis. This important property of the present invention allows for dynamic spectral equalization. Such equalization is important to

compensate for non-uniform gain associated with optical amplifiers in the optical networking system (e.g., erbium-doped fiber amplifiers). The principle of the present invention that allows for spectral equalization is detailed in Figures 20 and 21. The model results in these figures derive from an extension of the ray trace model of the system shown in Figs. 13-14. In Figure 20 it is seen that a 0.3-degree change in micromirror angle produces significant translational walk-off of a representative collimated beam (representing one wavelength channel in the system). However, the 0.3-degree deflection is only a fraction of the 1.15 degrees it takes to move the beam to an adjacent output port. The change in coupling efficiency with micromirror angle is shown in Figure 21. Under servo control, each wavelength in the system can be coupled with any efficiency value by making a suitable adjustment in the associated micromirror deflection angle in accordance with Figure 21. In this way the device of the present invention provides variable optical attenuation at the granularity of a single wavelength.

Servo Control System

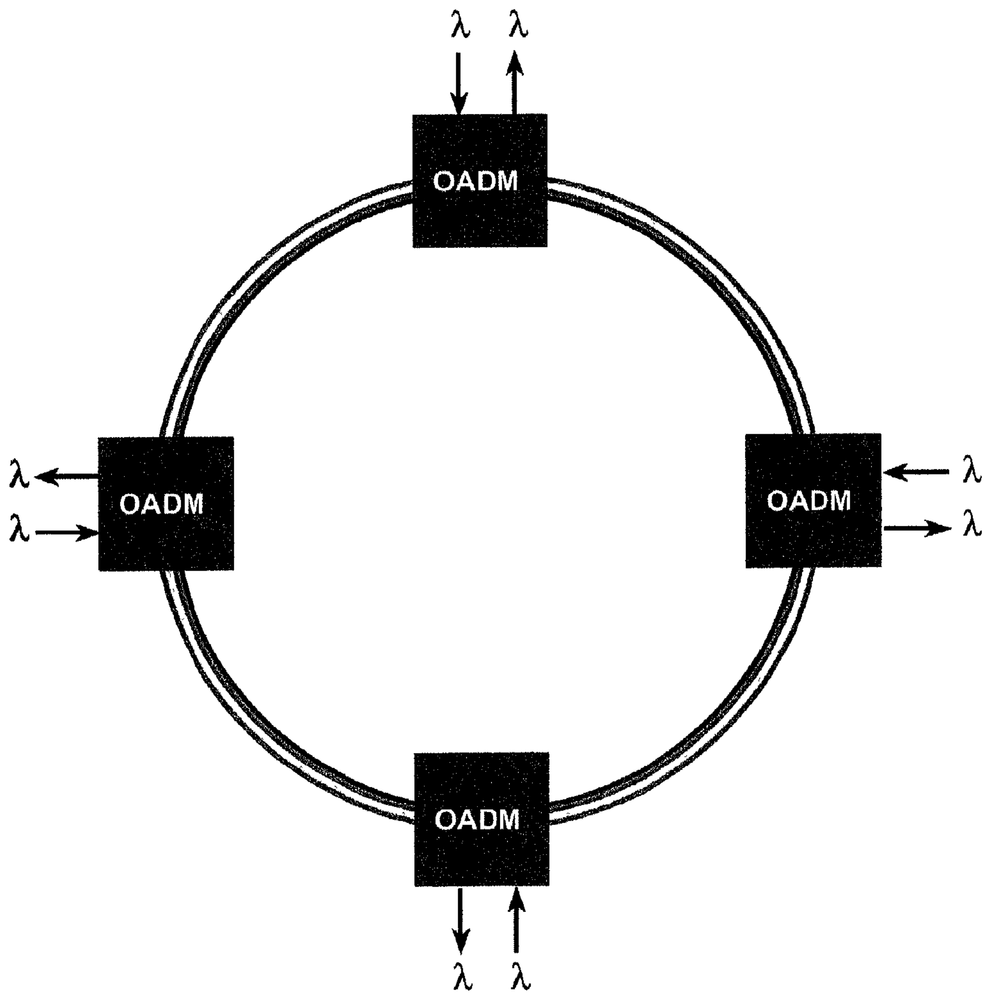
To facilitate feedback control of the dynamic mirrors (in the micromirror array and in the 2-axis mirror array for improved collimator coupling), a suitable feedback signal is required. Figure 22 illustrates the manner in which the present invention provides the requisite signals. Because the pass-through port contains multiple wavelengths, a portion of the outgoing light from this collimator is tapped off and sent to a spectral monitor. The spectral monitor can comprise a grating and linear photodiode array for example. Such spectral monitors are commercially available. The output from the spectral monitor provides a measure of the intensity of each wavelength channel in this port. If the drop ports only contain a single wavelength, then simple power monitoring of each drop port is sufficient. These signals are provided to a servo system that controls the driving voltages to each of the mirrors in the system. The mirrors are actuated in such a way as to achieve whatever coupling conditions are desired on a channel-by-channel basis. For example, spectral equalization would require equal intensity set points of all pass-through channels.

It is understood that the specific device design described here is only representative of the general device architecture, and that other similar designs may be implemented to achieve substantially the same results.

References

1. J. Ford *et al.*, Journal of Lightwave Technology **17**, pp. 904-911 (1999).
2. K. E. Petersen, Proc. IEEE **70**, pp. 420-457 (1982).
3. A. P. Neukermans and T. G. Slater, US Patent 5,629,790 (1997).

Dynamic OADMs



- **Dynamic network reconfiguration under software control**

- **Allows <u>any</u> λ to be added or dropped at <u>any</u> node**

Figure 1

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Telecom Market Segments

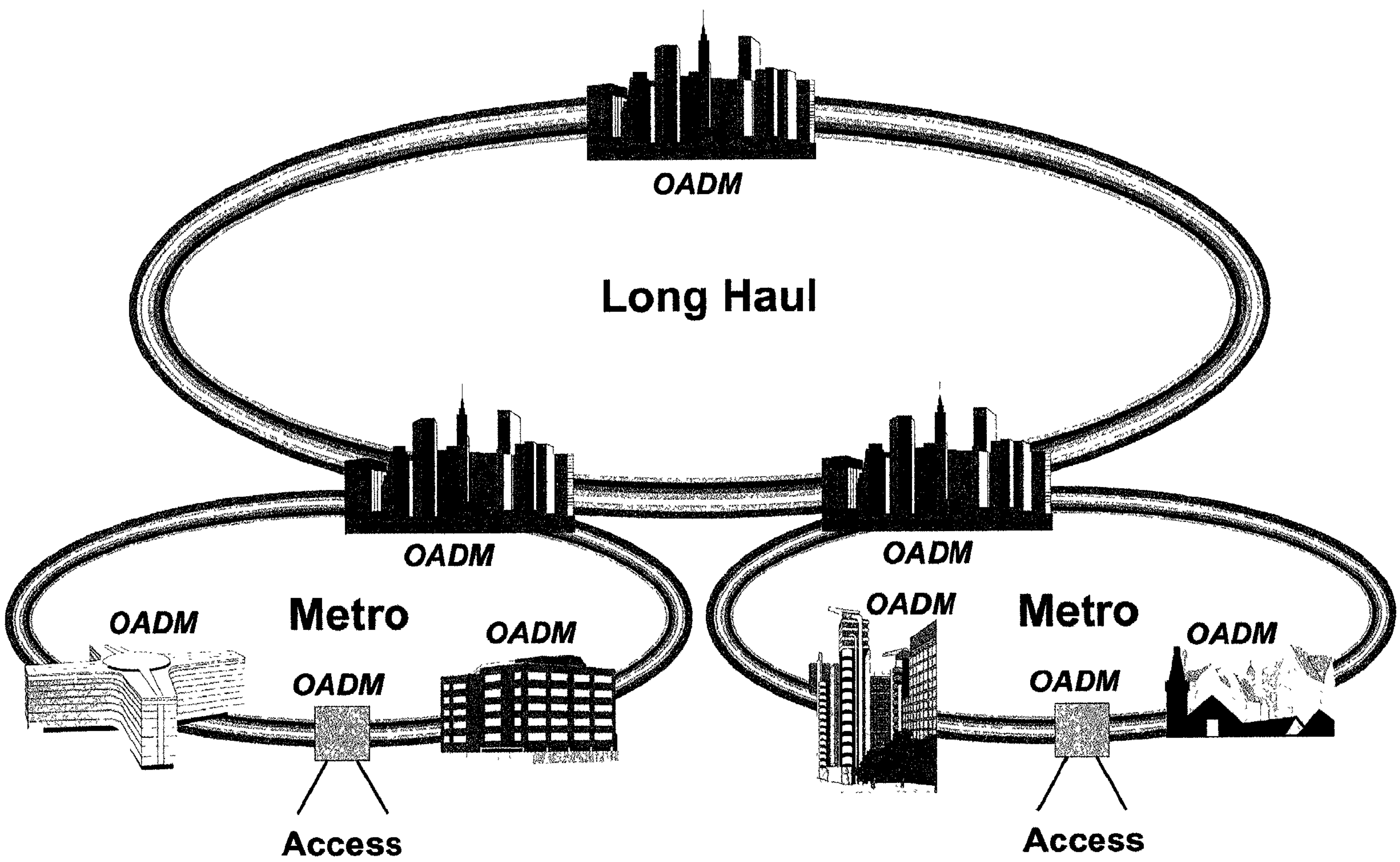

Figure 2

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Dynamic Add/Drop Architectures

Parallel Architecture | Serial Architecture

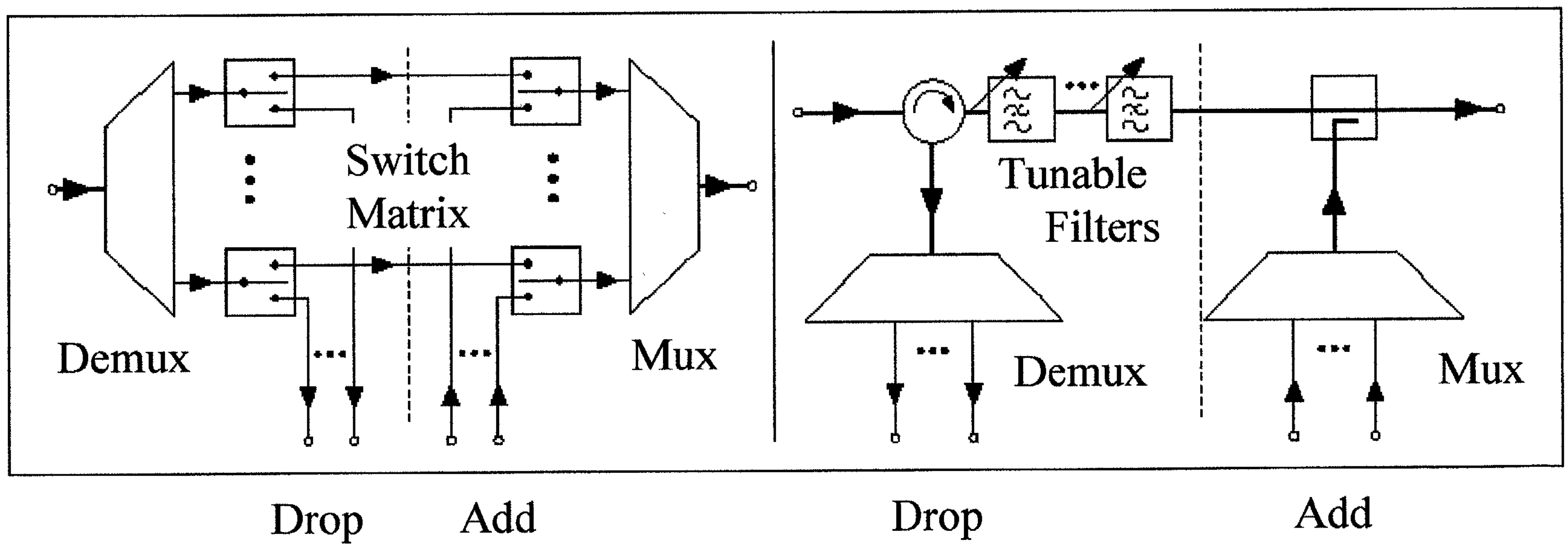


Figure 3

Parallel vs Serial Architectures

- Parallel
  - Requires demux of all channels.
  - Scalable for high channel count.
- Serial
  - In use today for fixed, low-channel-count systems.
  - Significant losses may accumulate (scales as number of drop channels).
  - Through-channel disruption occurs during reconfiguration.
  - Requires demux of all channels on drop port (even though only a small portion of channels exist on drop fiber → significant additional costs).

Figure 4

Existing Add/Drop Architecture

- Utilizes the power of free-space optics to provide parallel manipulation of individual wavelengths in a compact architecture.
- 4-fiber device: Input, Pass-Through, Add, & Drop.
- Add & Drop fibers contain multiple wavelengths.
- Limitation: Add/Drop wavelengths must be multiplexed/demultiplexed → Significant additional cost.

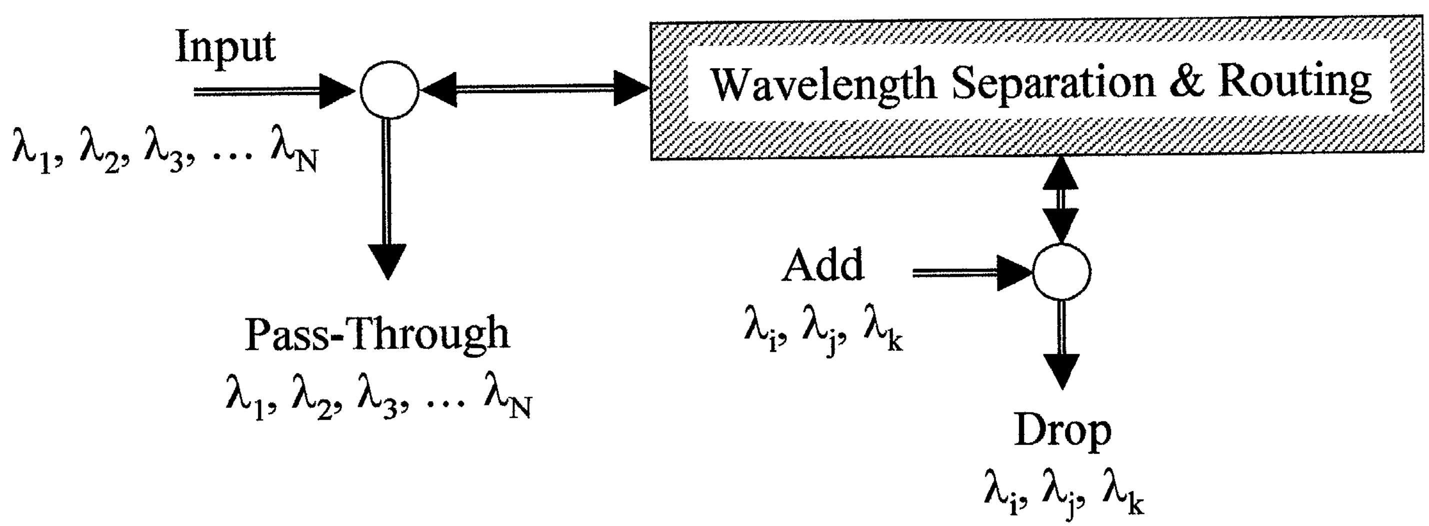
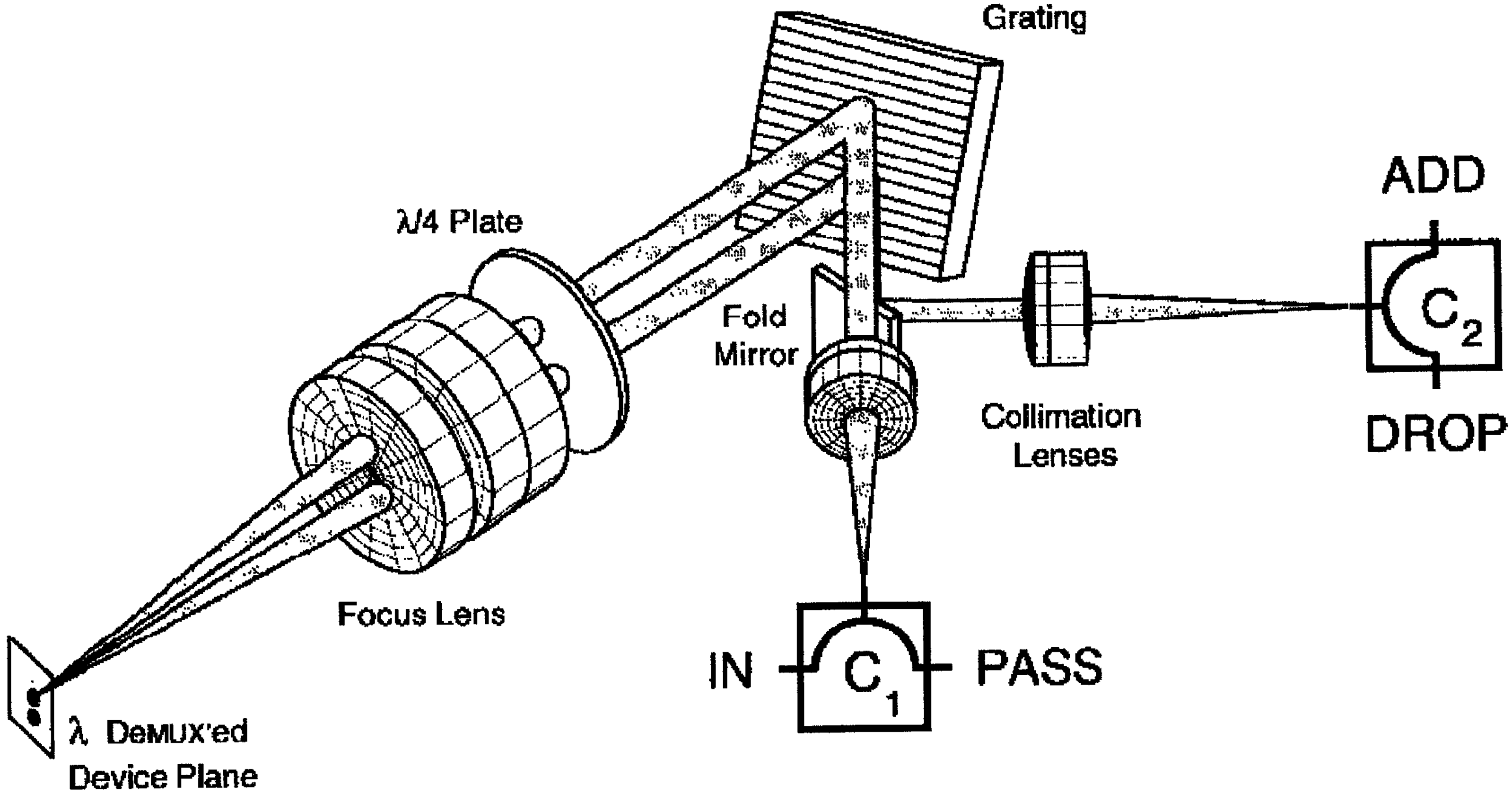


Figure 5

Dynamic OADM Architecture (Prior Art)



Ref: J. Ford *et al.*, JLT **17**, pp. 904-911 (1999)

Figure 6

Capella OADM Approach (using Combiner)

- Multiple Drop Ports
  - Provide physically distinct Drop ports
  - Benefit: Eliminates the need to mux/demux add/drop ports
- Servo Control
  - Provides for dynamic equalization
  - Minimize loss through optimum alignment
  - Low-cost assembly

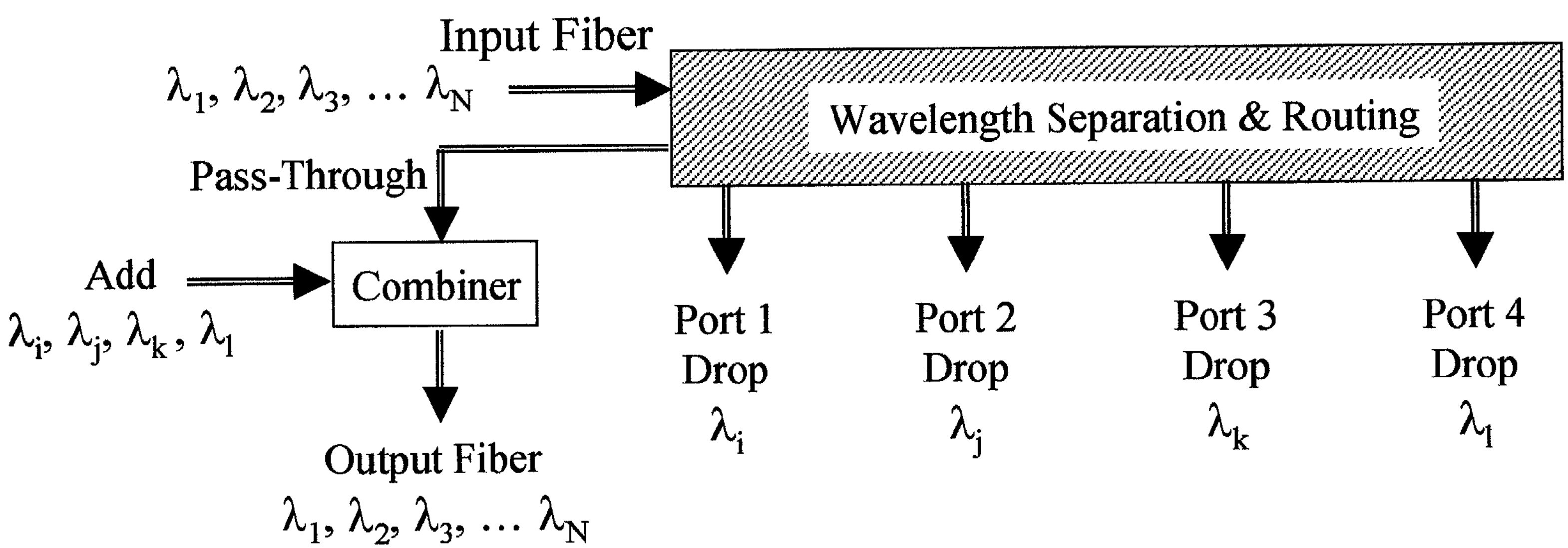


Figure 7

Bi-Directional Dynamic OADM (Reciprocal Scheme)

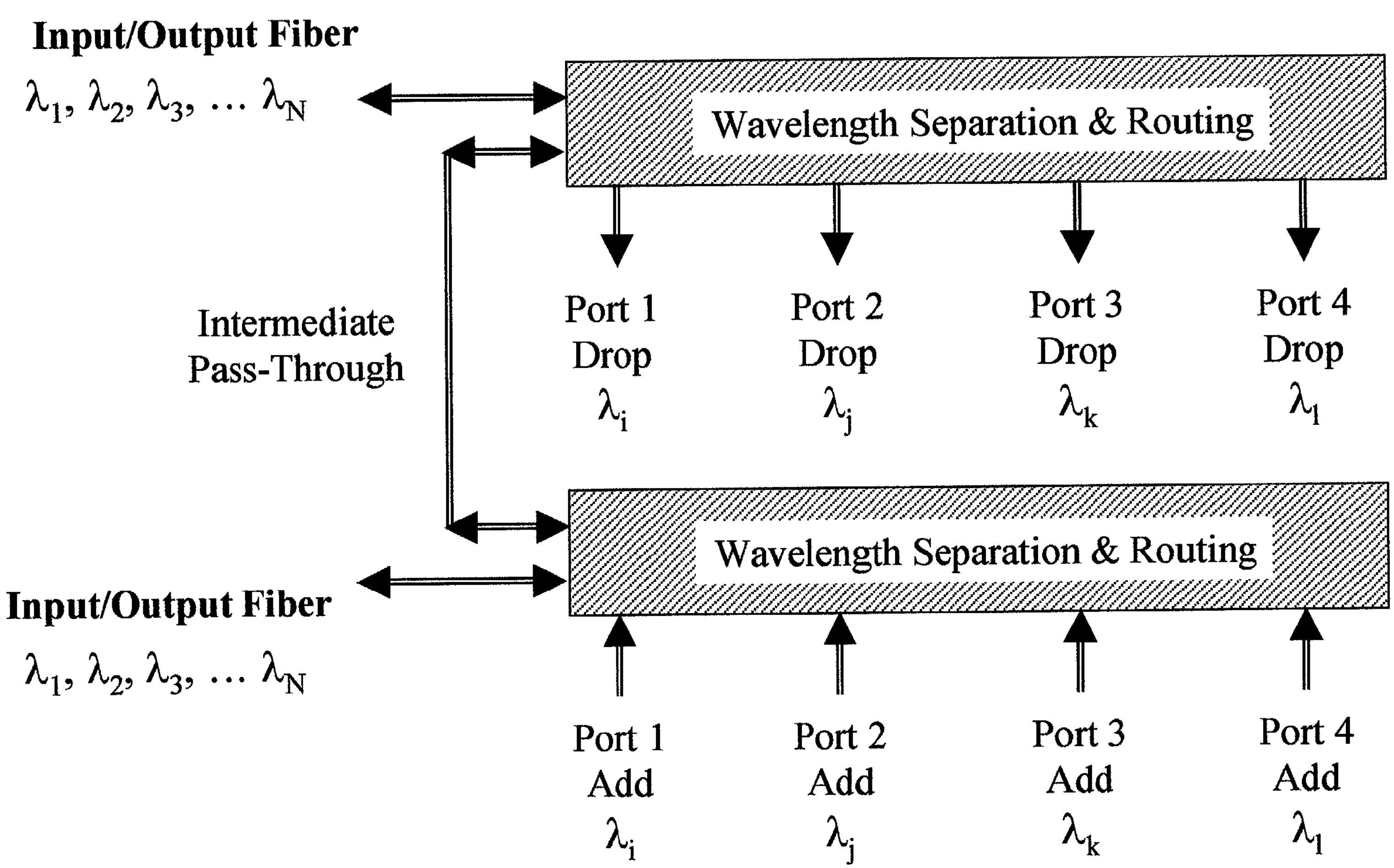


Figure 8

Bi-Directional OADM Approach (Circulator Scheme)

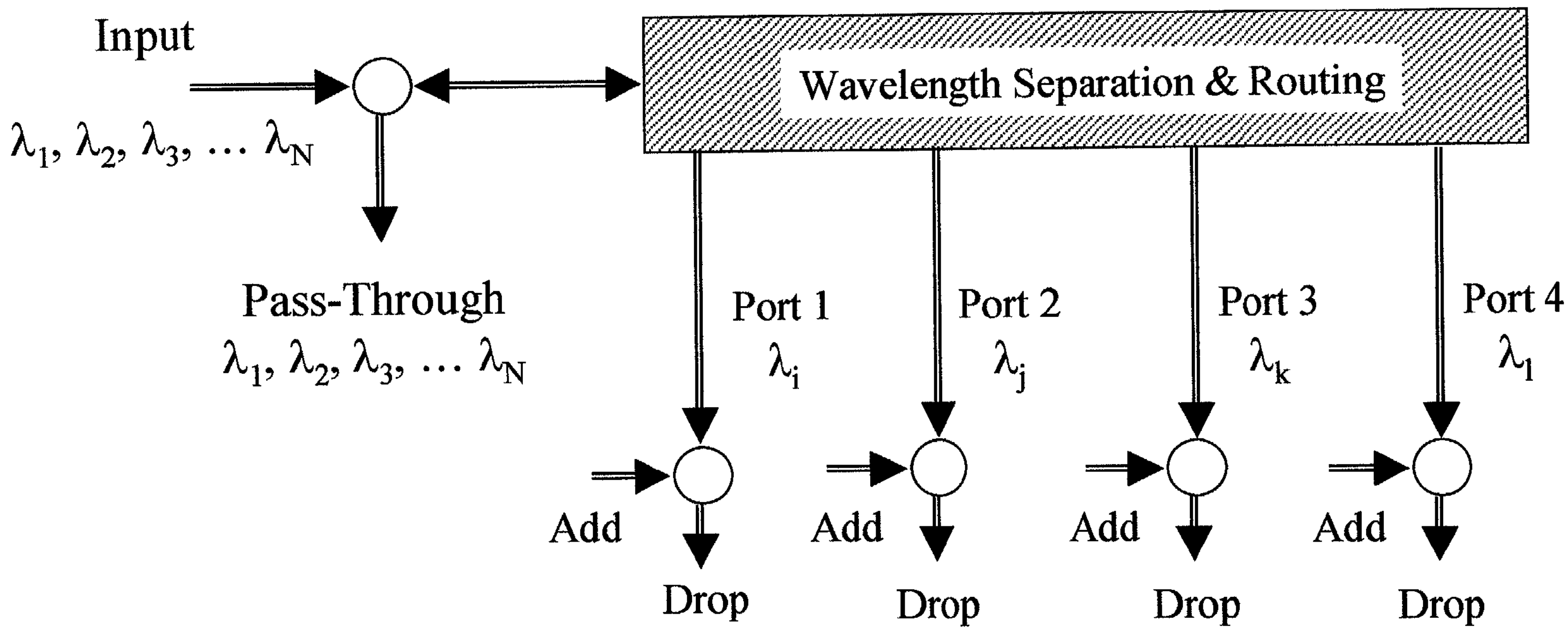


Figure 9

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Capella Photonics OADM Design

(3-Wavelength System Illustration)

Legend
Orange = 1527 nm
Red = 1545 nm
Green = 1563 nm

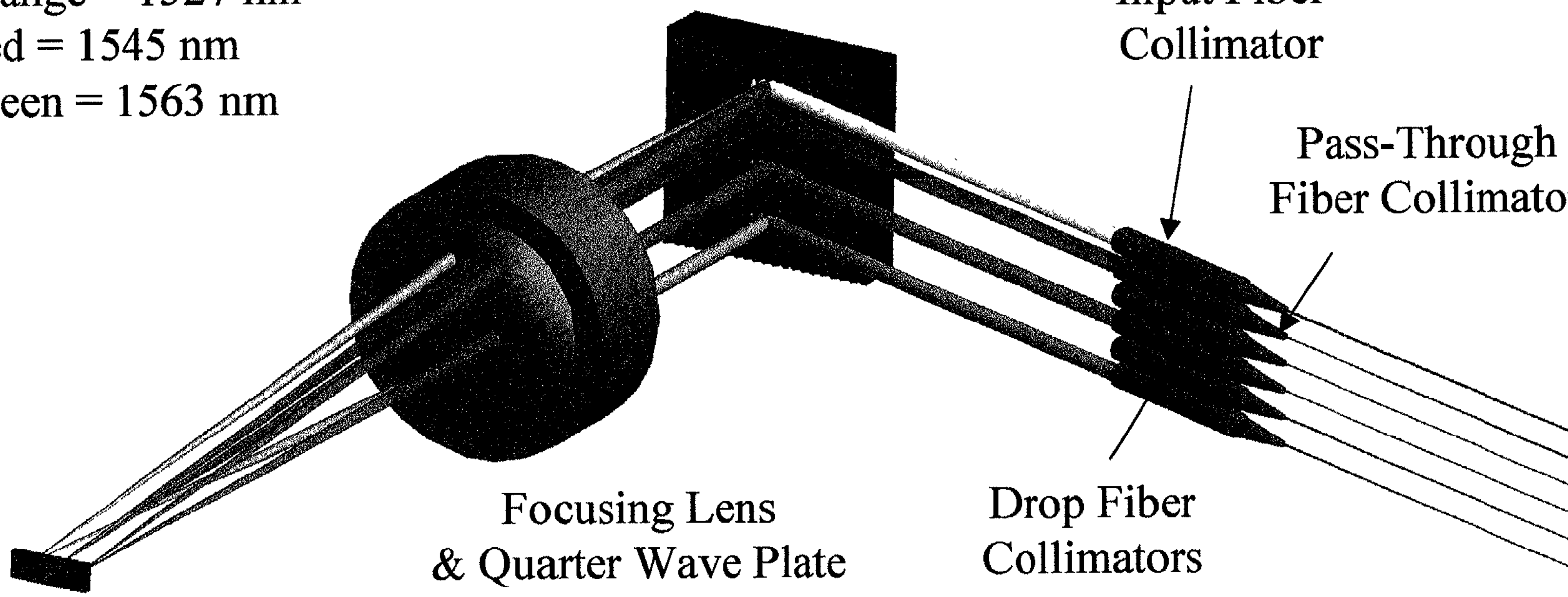

Figure 10

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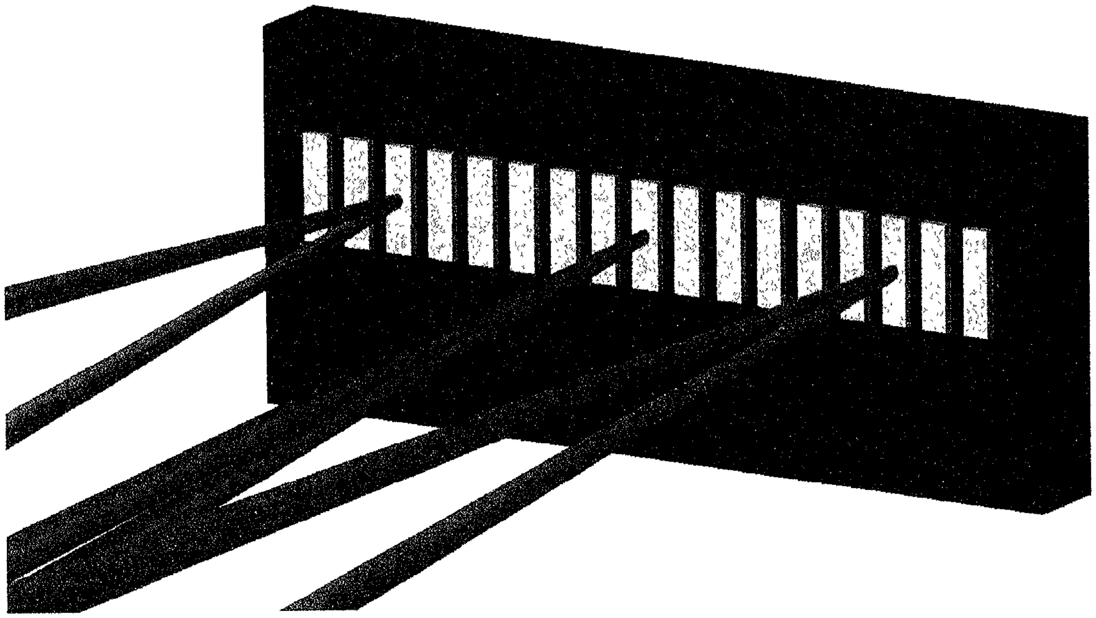
Micromirror Array



Micromirror array provides channel-by-channel wavelength routing and dynamic gain equalization.

Figure 11

Silicon Light Machines MEMS Ribbon Deflector Array

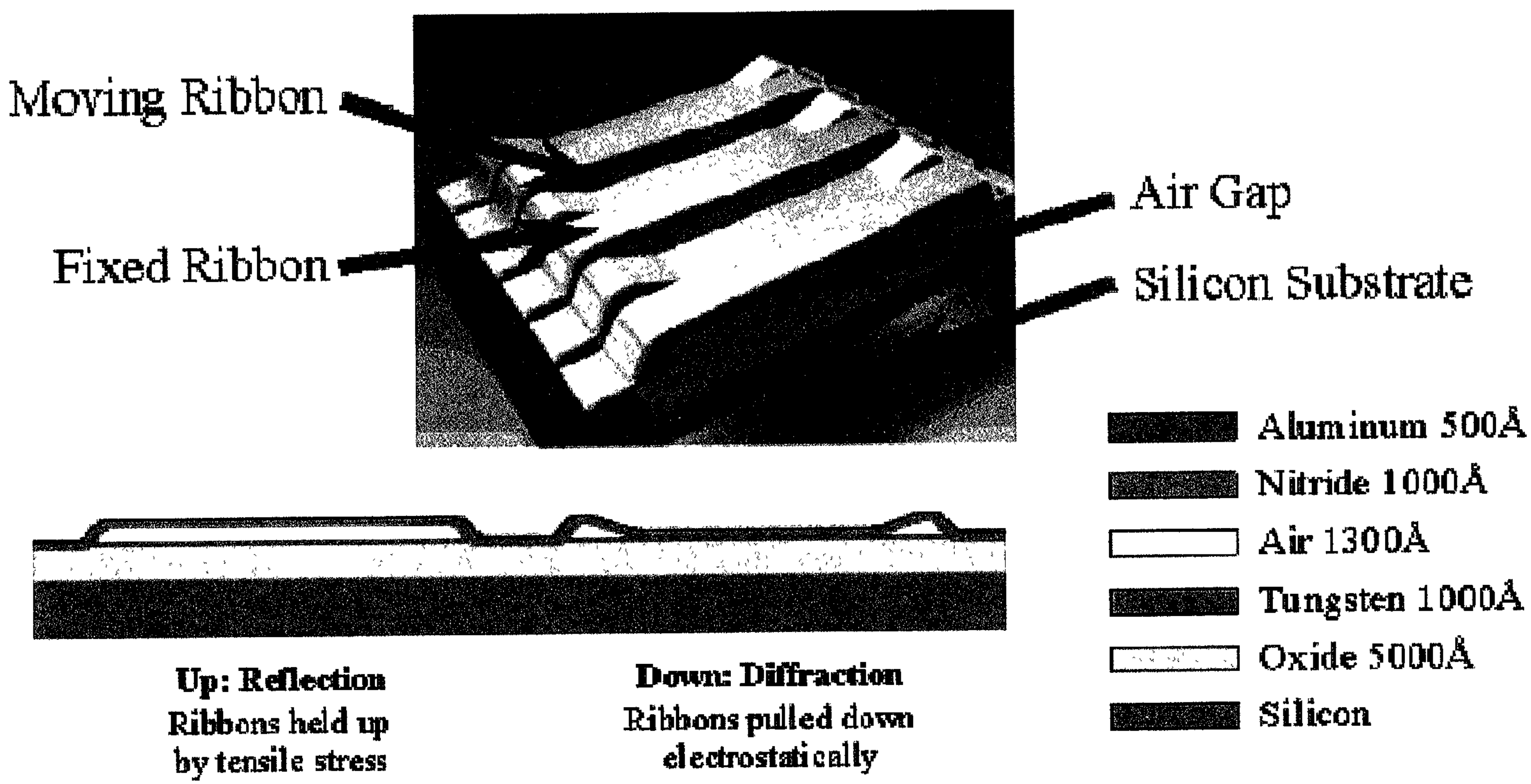


Figure 12

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Capella Photonics OADM Design

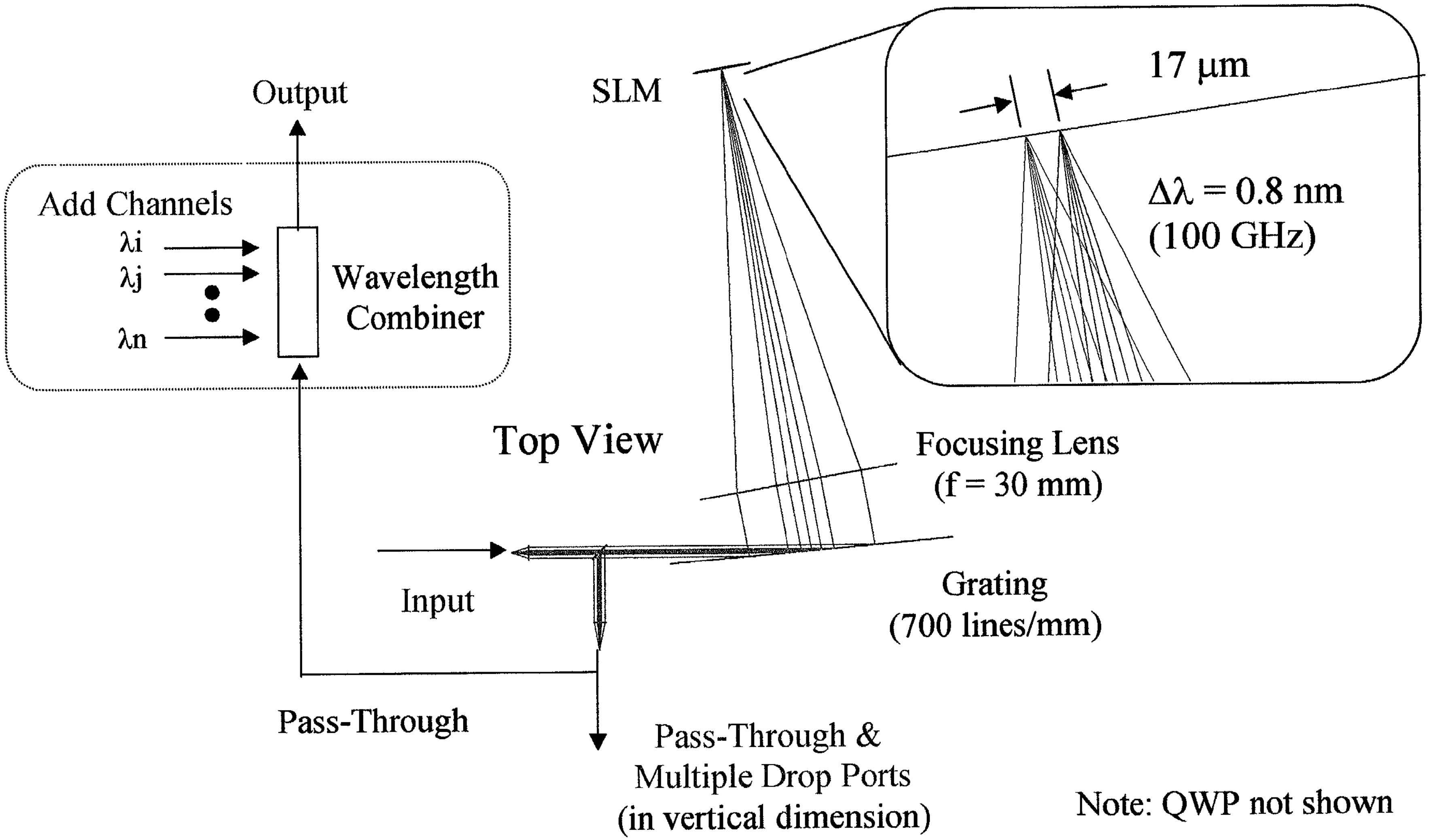

Figure 13

Note: QWP not shown

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Modified Dynamic OADM Design

- Use analog micromachined mirrors to steer individual wavelengths to the appropriate Drop ports.
- Servo control mirrors to ensure maximum coupling efficiency.

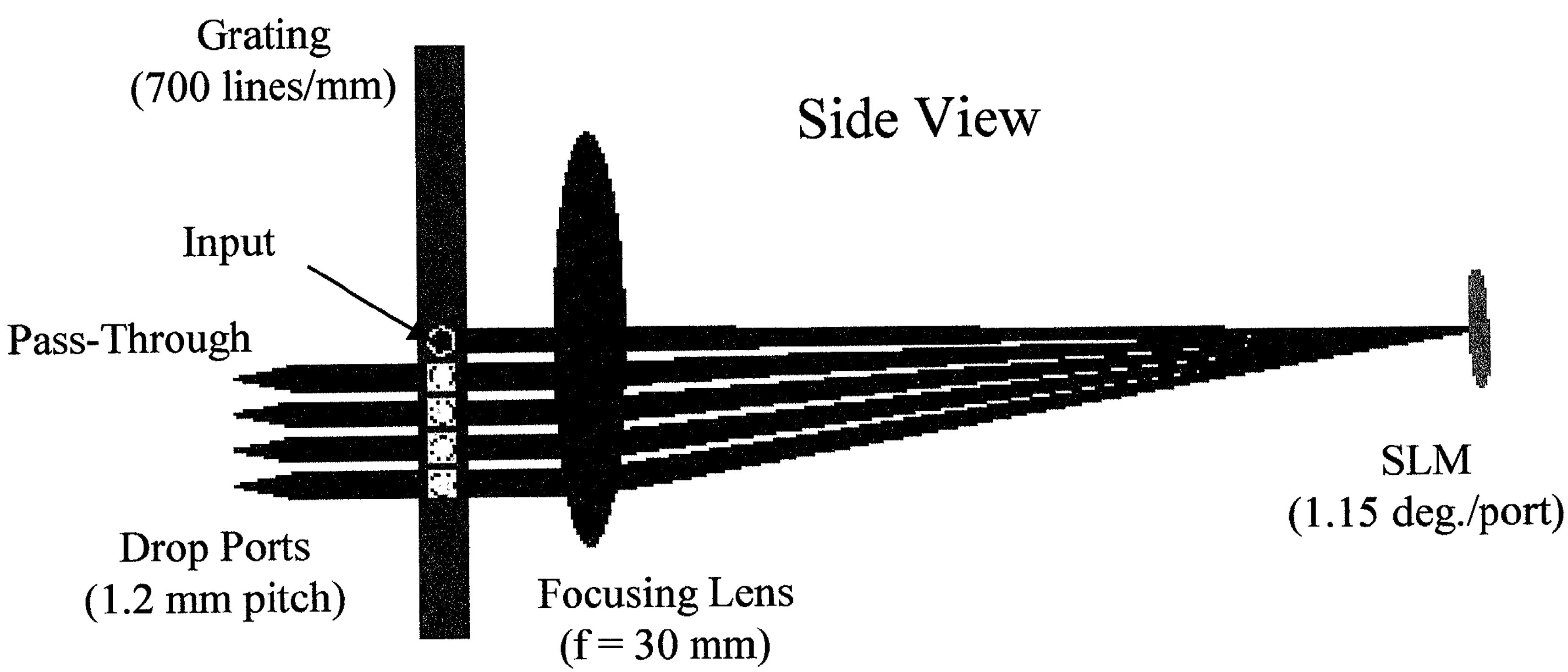

Figure 14

Focused Spot Intensity Distribution at SLM Plane for 100 GHz Channel Spacing ($\Delta\lambda = 0.8$ nm)

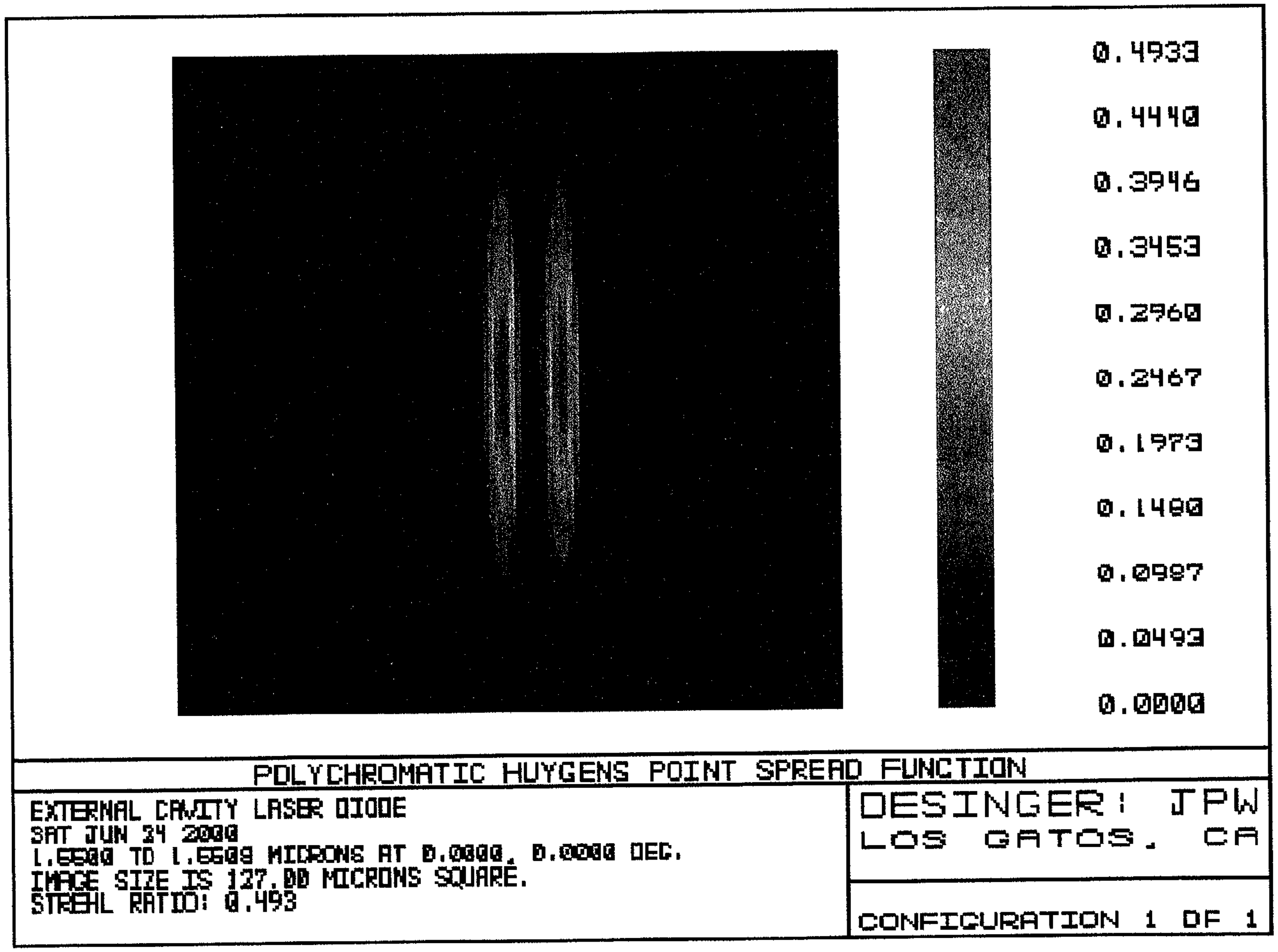

Figure 15

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4-f Telecentric Imaging System for Servo-Based Collimator Coupling

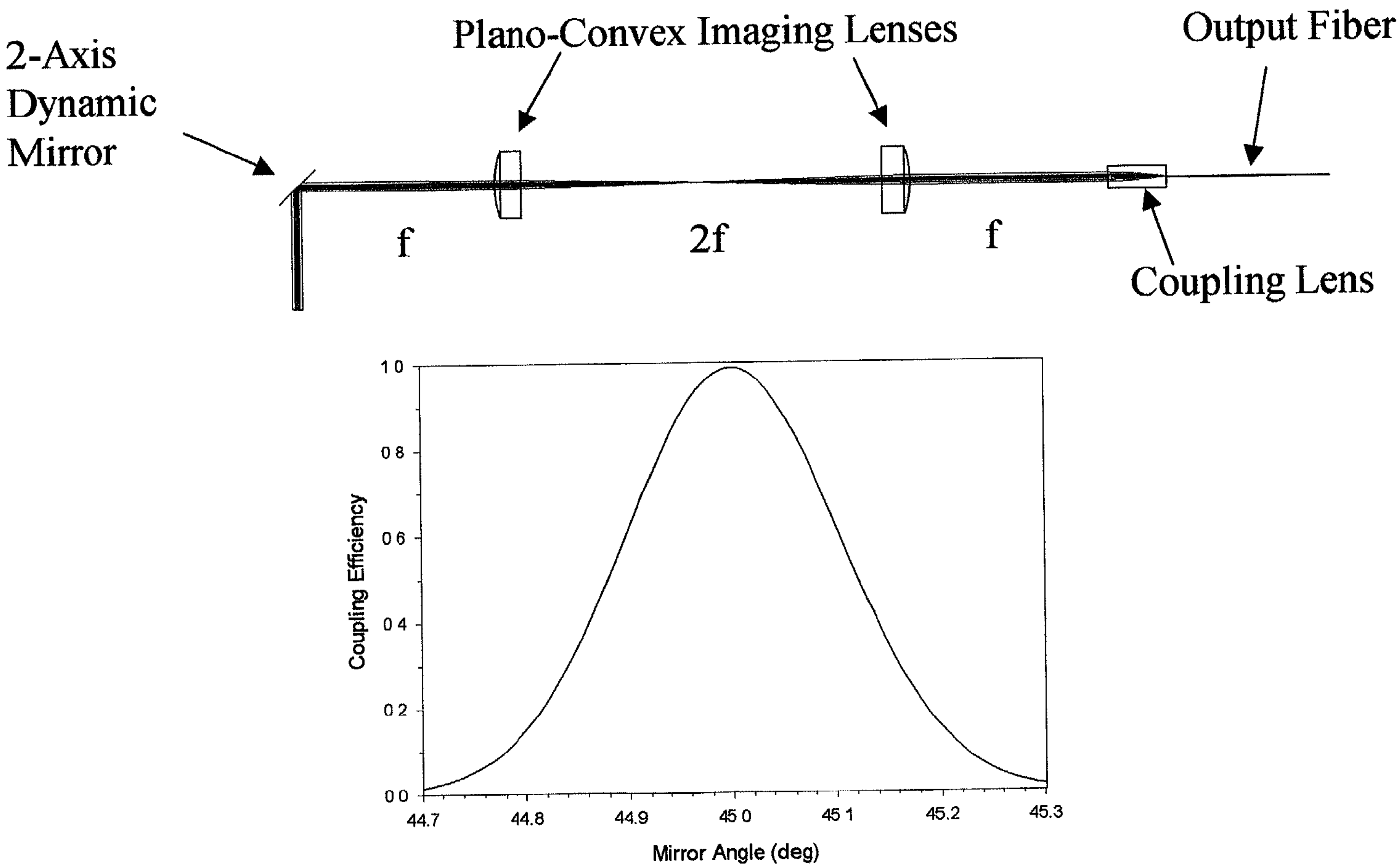

Figure 16

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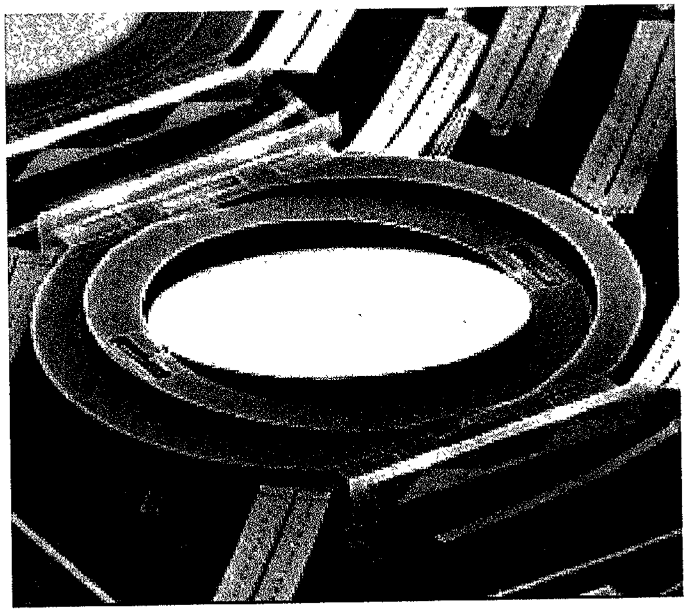
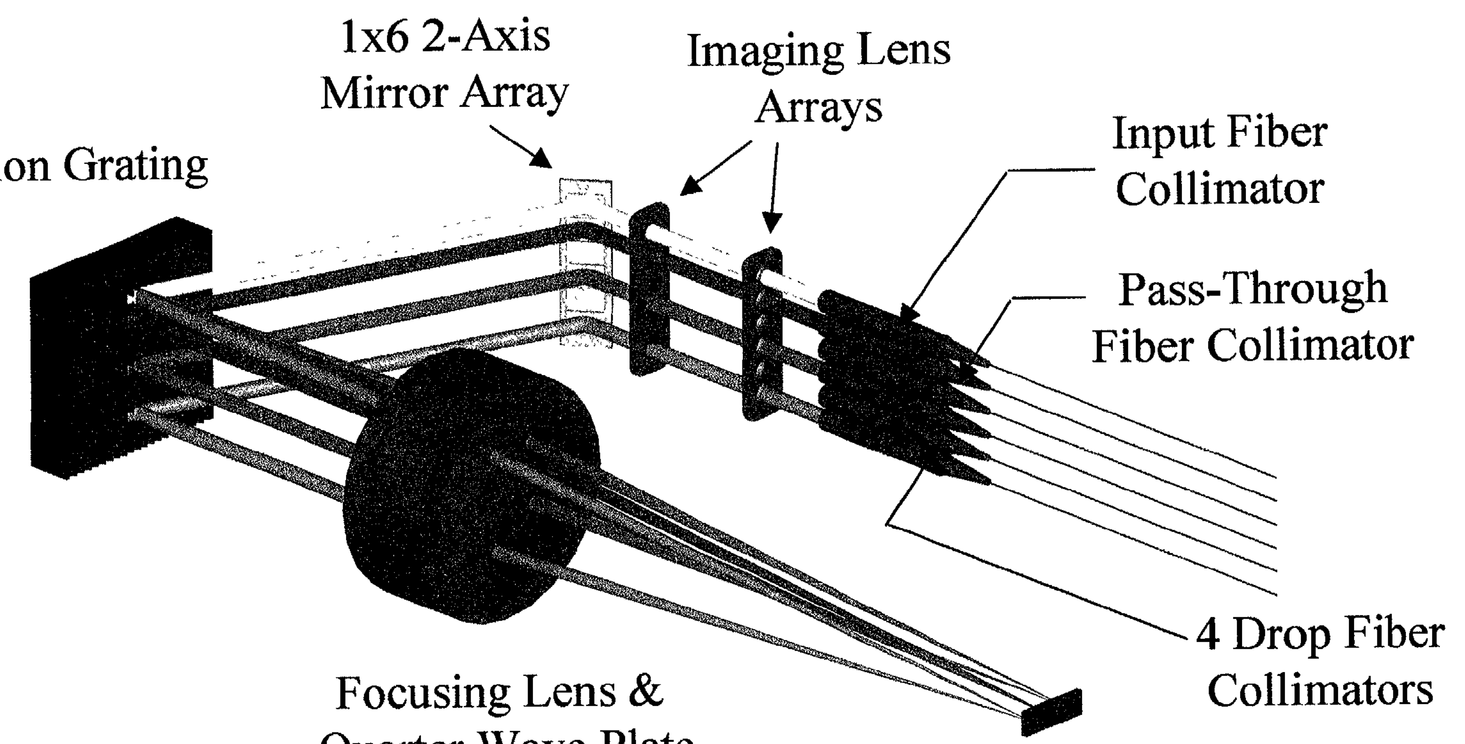
Prior Art 2-Axis Mirror



Lucent Technologies
Bell Labs Innovations

Figure 17

OADM Architecture with 2-Axis 1xN Mirror Array Actuation + Telecentric Imaging Lens Arrays



<u>Legend</u>
Orange = 1527 nm
Red = 1545 nm
Green = 1563 nm

Figure 18

2-D Input/Output Collimator Array for Increased Port Count

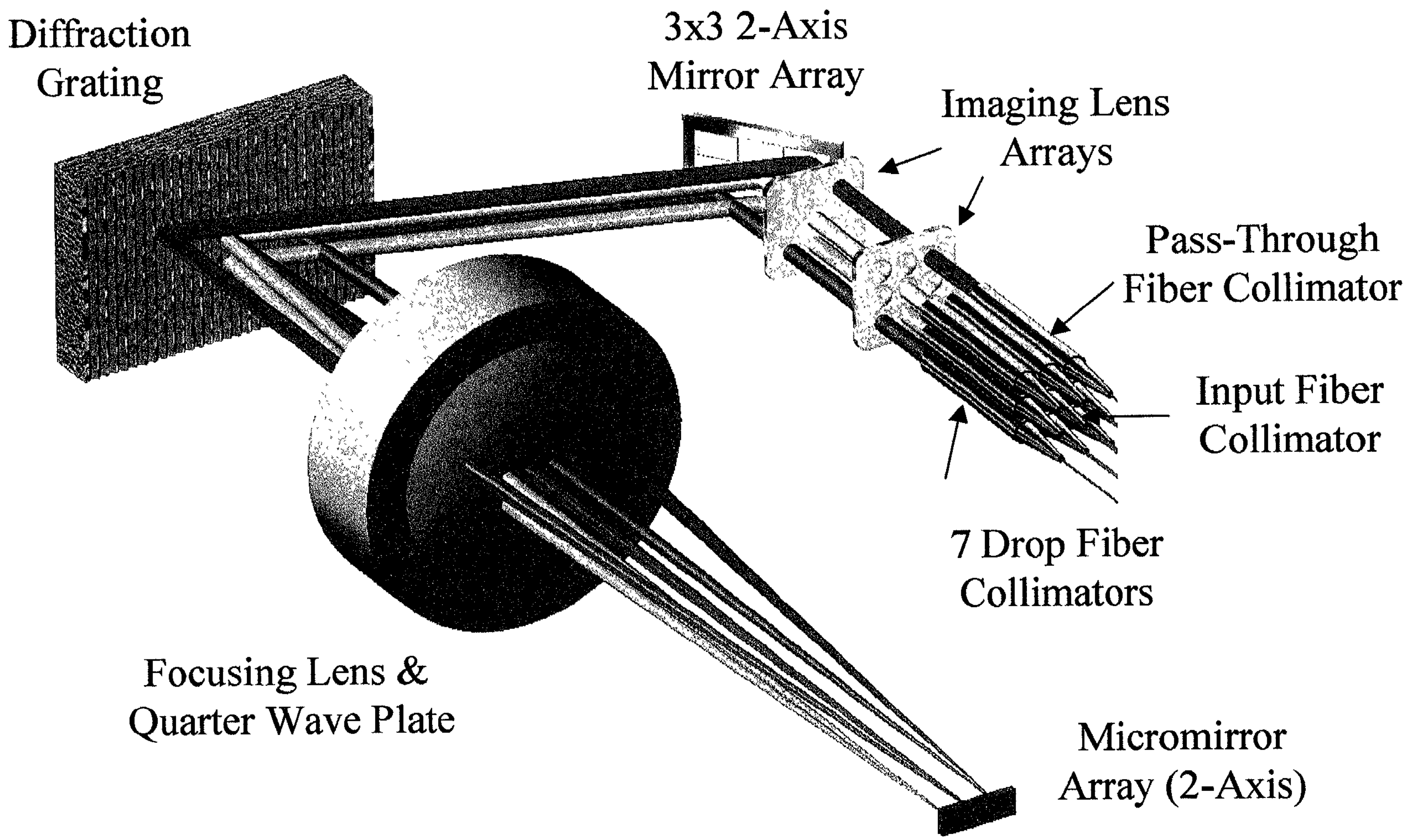


Figure 19

Change in Coupling with Mirror Position

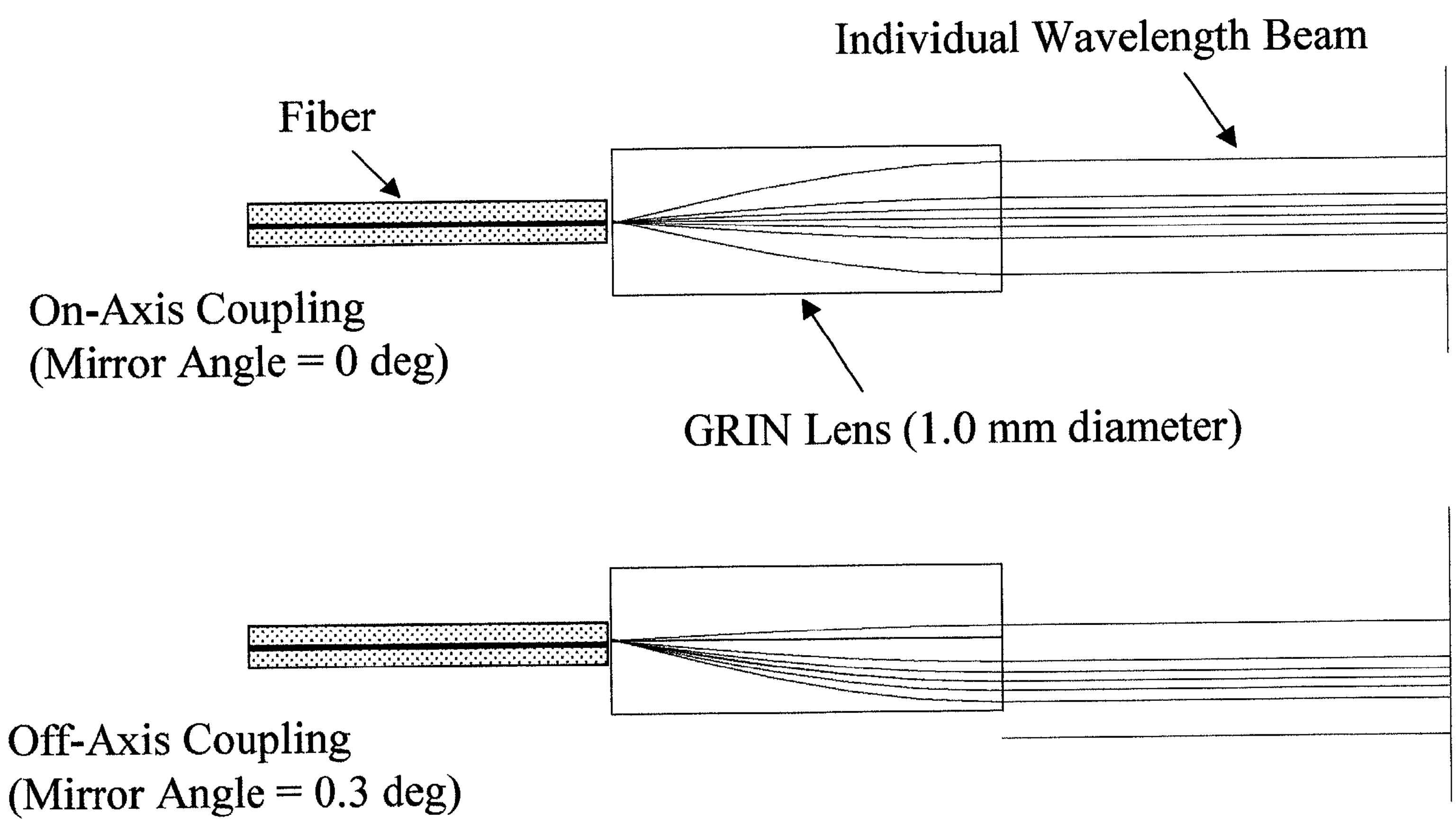


Figure 20

Change in Coupling with Mirror Angle

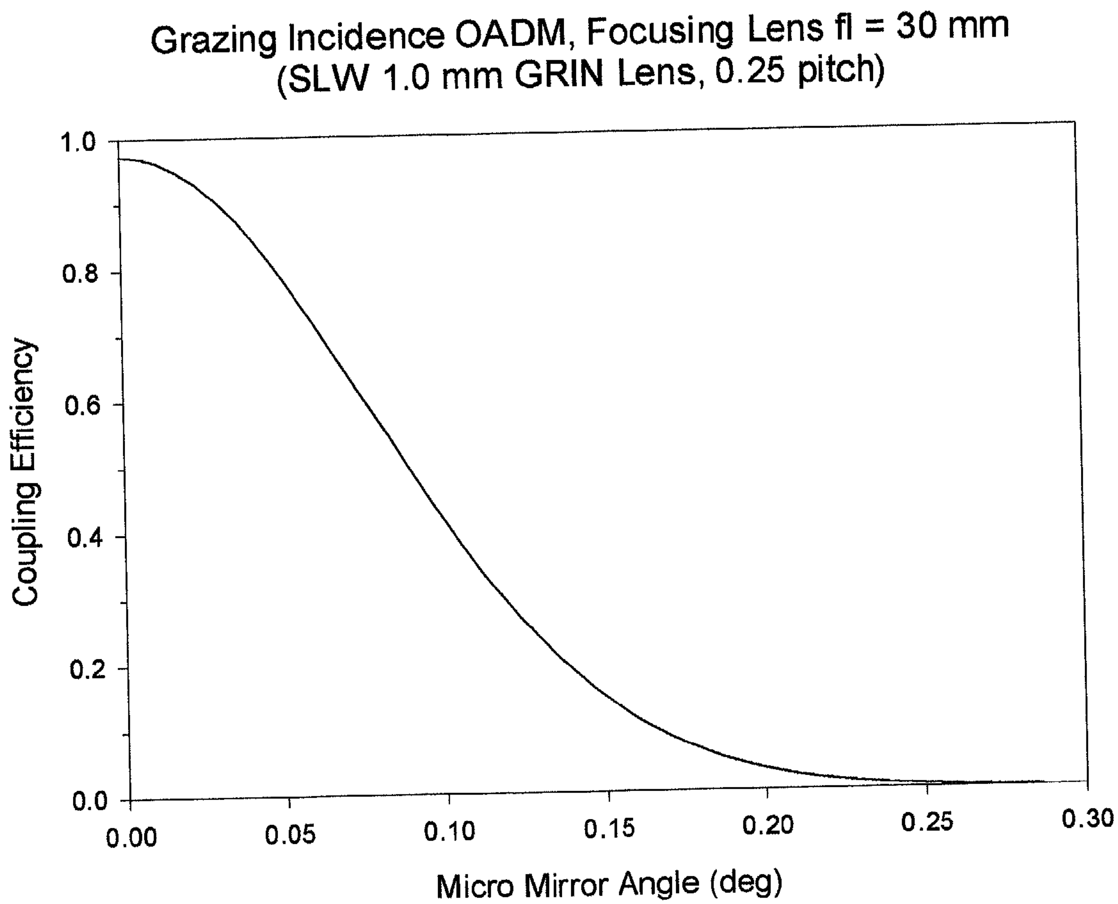


Figure 21

Servo Block Diagram
(for configuration & equalization control)

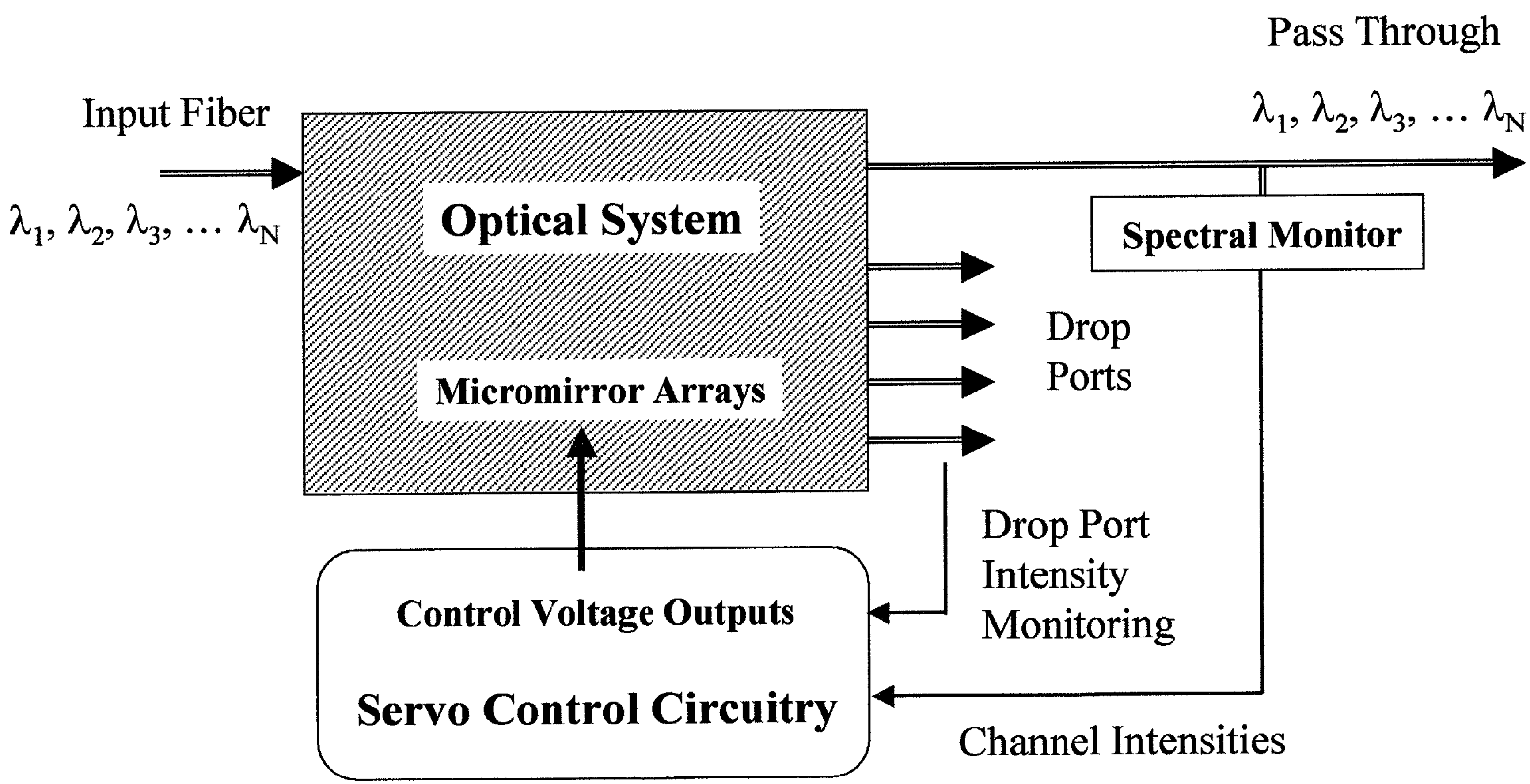
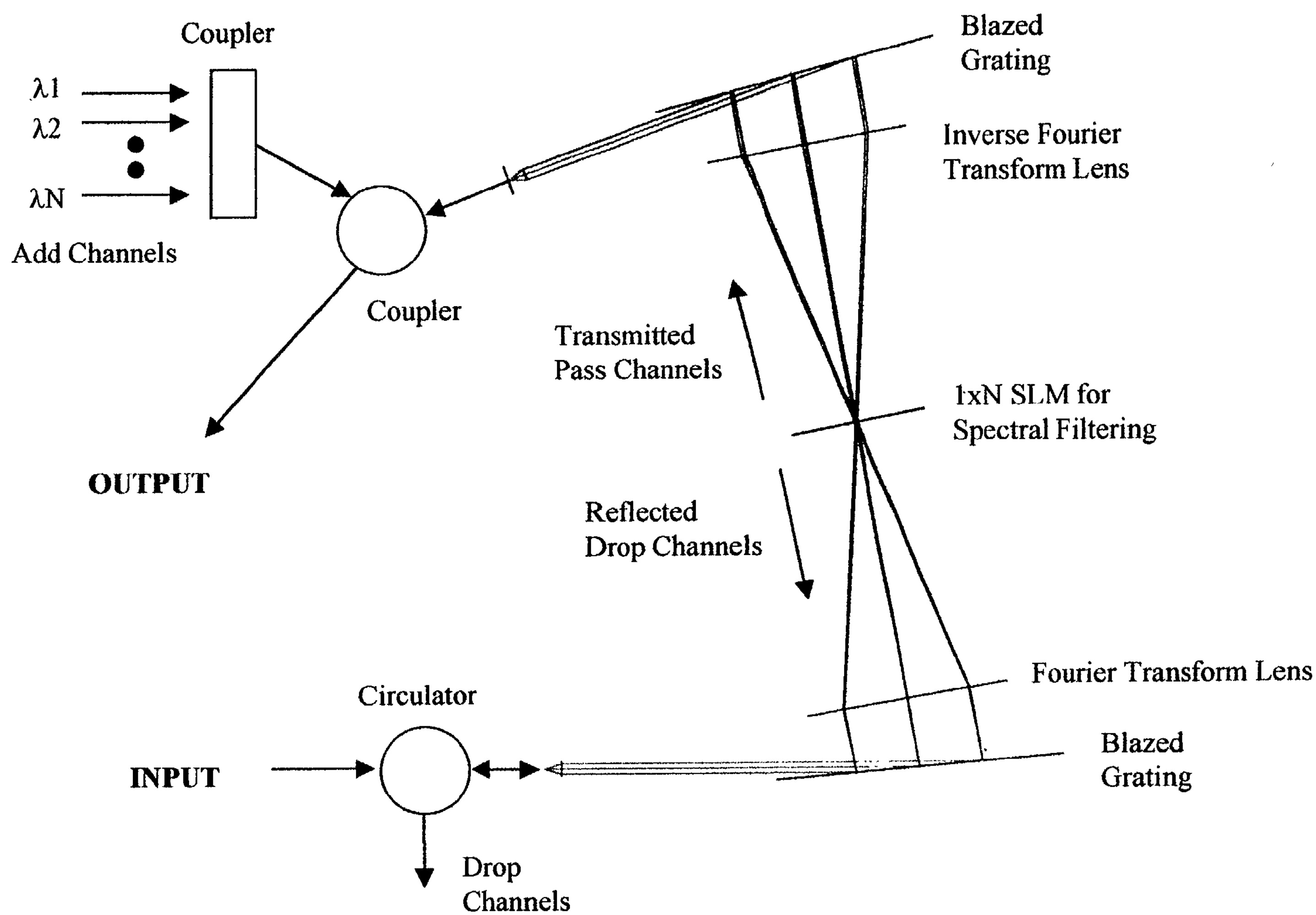


Figure 22

Appendix A

Design Concept for DWDM Multi-Channel Dynamic Add/Drop Module, dated 7/28/00

Design Concept for DWDM Multi-Channel Dynamic Add/Drop Module

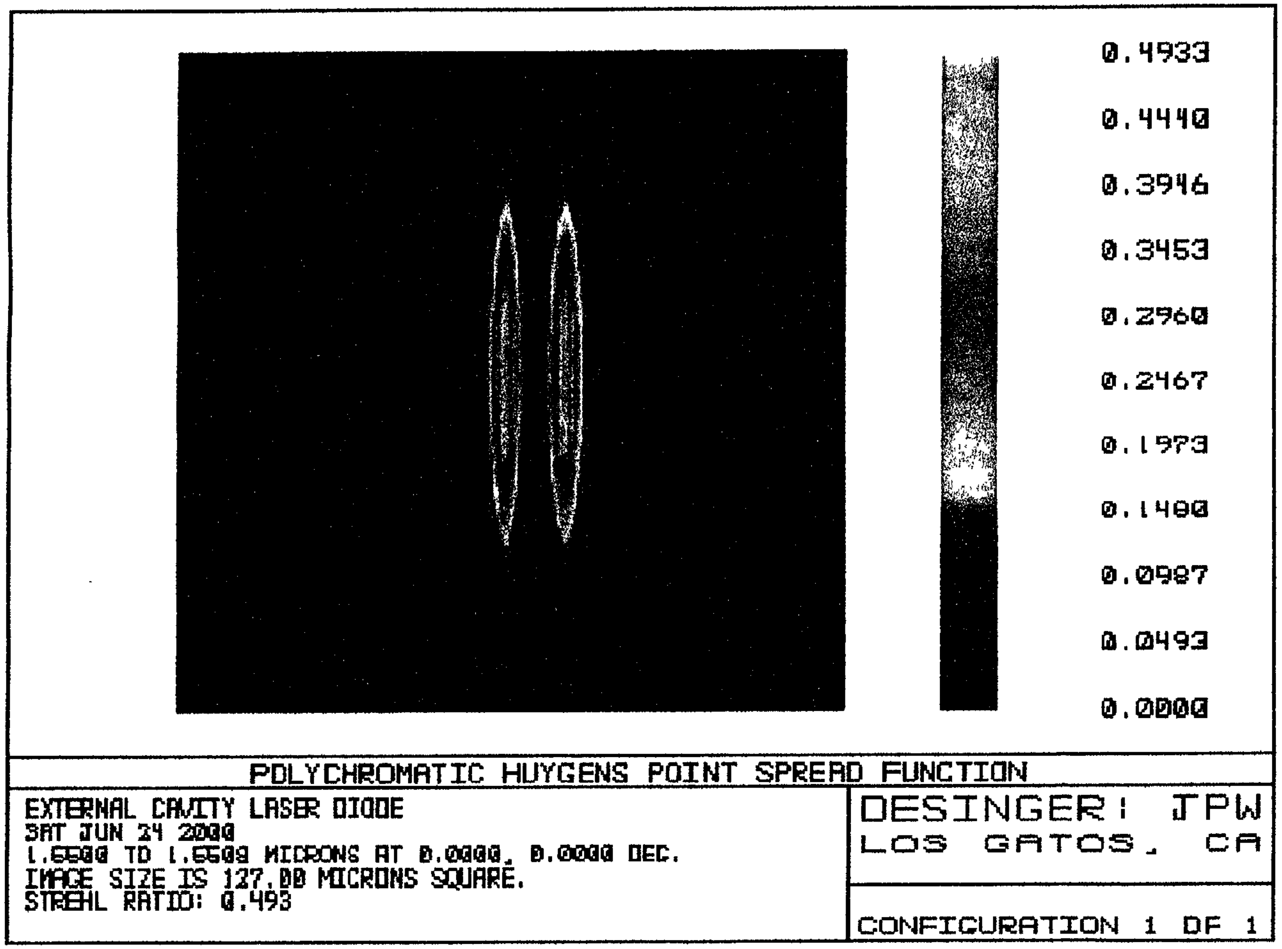


Inventor: Jeffrey P. Wilde
Jeffrey P. Wilde 7/28/00

Witness: Read and Understood
Mark H. Garrett 7-28-00

Date: 7/28/00

Focused Spot Intensity Distribution at SLM Plane for 100 GHz Channel Spacing ($\Delta\lambda = 0.8$ nm)



Inventor: Jeffrey P. Wilde
Jeffrey P. Wilde
7/28/00

Witness: Read & Understood
Mark H. Garrett
7.28.00

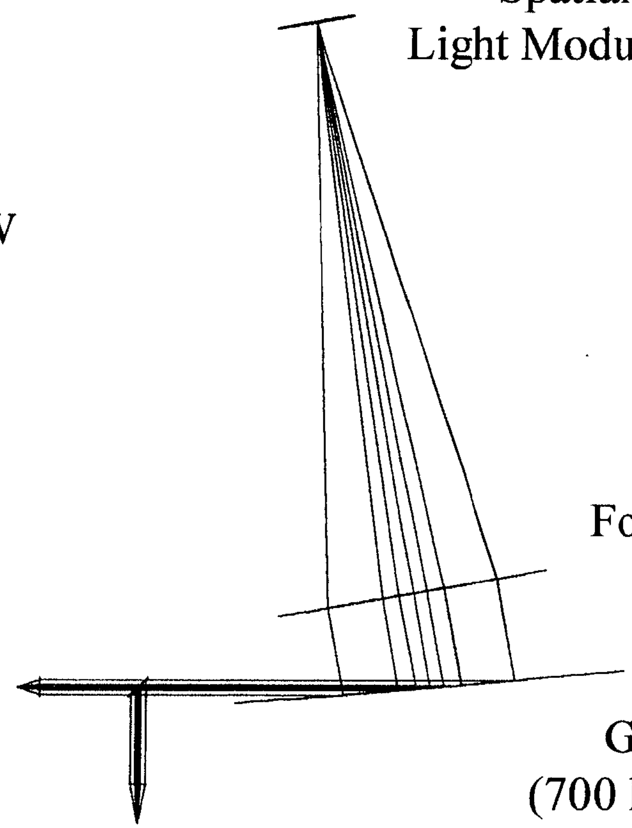
Date: 7/28/00

Appendix B

Modified Dynamic OADM Design, by J. P. Wilde, 11/28/00

Modified Dynamic OADM Design

Top View



Witnessed by:
Jeff Drazan
+ Ben Yu

11/28/00

Jeffrey P. Wilde

Jeffrey P. Wilde 11/28/00

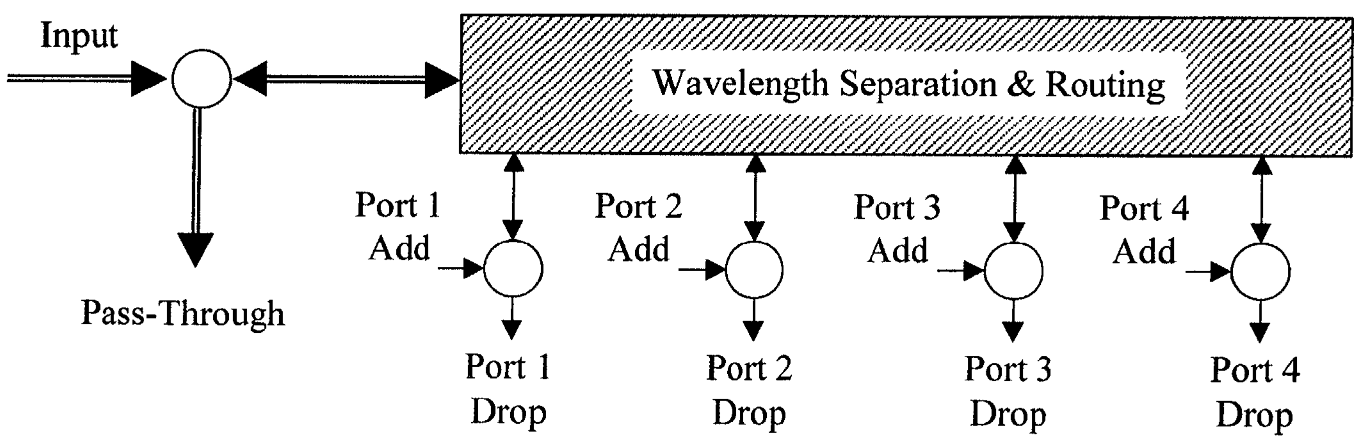
11/28/00.

Date: 11/28/00

11

New Design with Multiple Add/Drop Ports

- Objective: Utilize the power of free-space optics to provide a more versatile architecture with multiple add/drop ports in one package.
- Target Configuration:
  - 4 to 8 physically separate add/drop ports
  - Each port can add & drop multiple wavelengths
  - Each port requires a circulator to separate the add & drop channels
- Benefit: Eliminates the need to demultiplex and switch wavelengths at the final destination.



Jeffrey P. Wilde 11/28/00

10/28/00

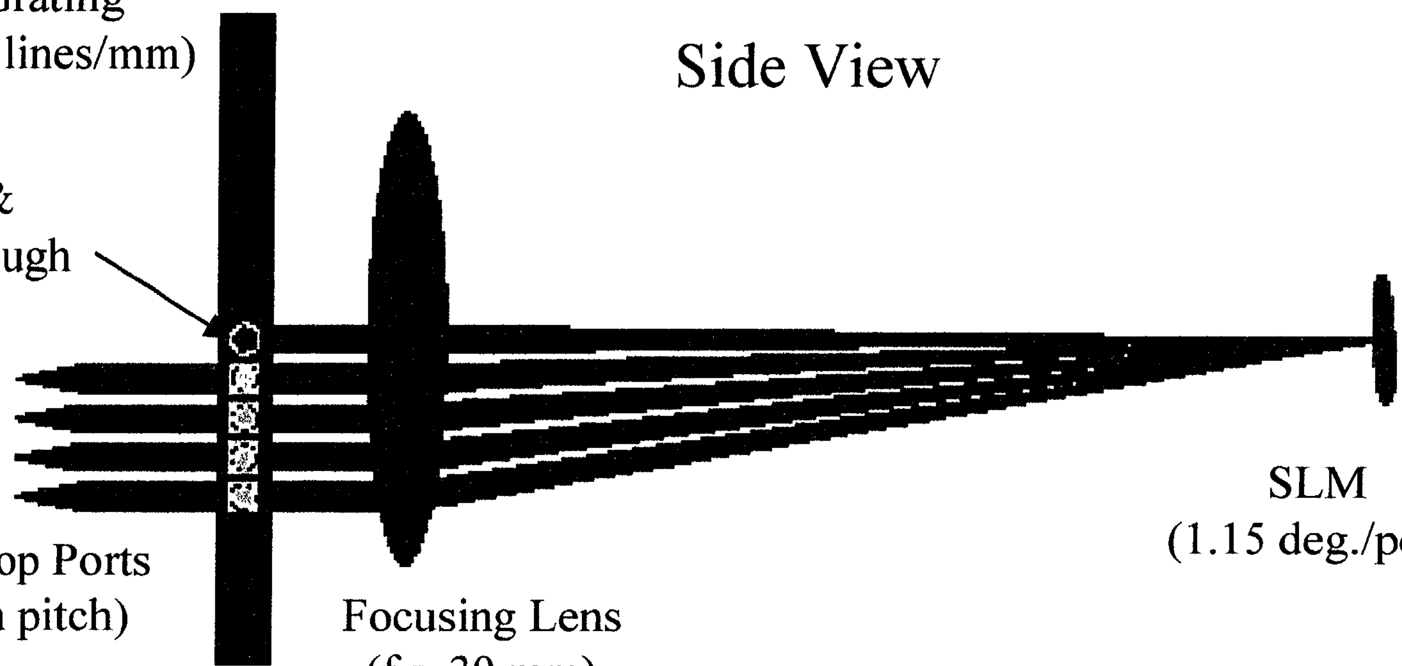
Date: 11/28/00

11/28/00

12

Modified Dynamic OADM Design

- Use analog micromachined mirrors to steer individual wavelengths to the appropriate Drop ports.
- Servo control mirrors to ensure maximum coupling efficiency.
- The Add ports will then be automatically aligned to the Pass-Through port.



Jeffrey P. Wilde Jeffrey P. Wilde 11/28/00

11/28/00.

Date: 11/28/00

11/28/00

CAP-101/PROV

Appendix C:

Reconfigurable OADM with Dynamic Equalization, by J. P. Wilde, 12/28/00

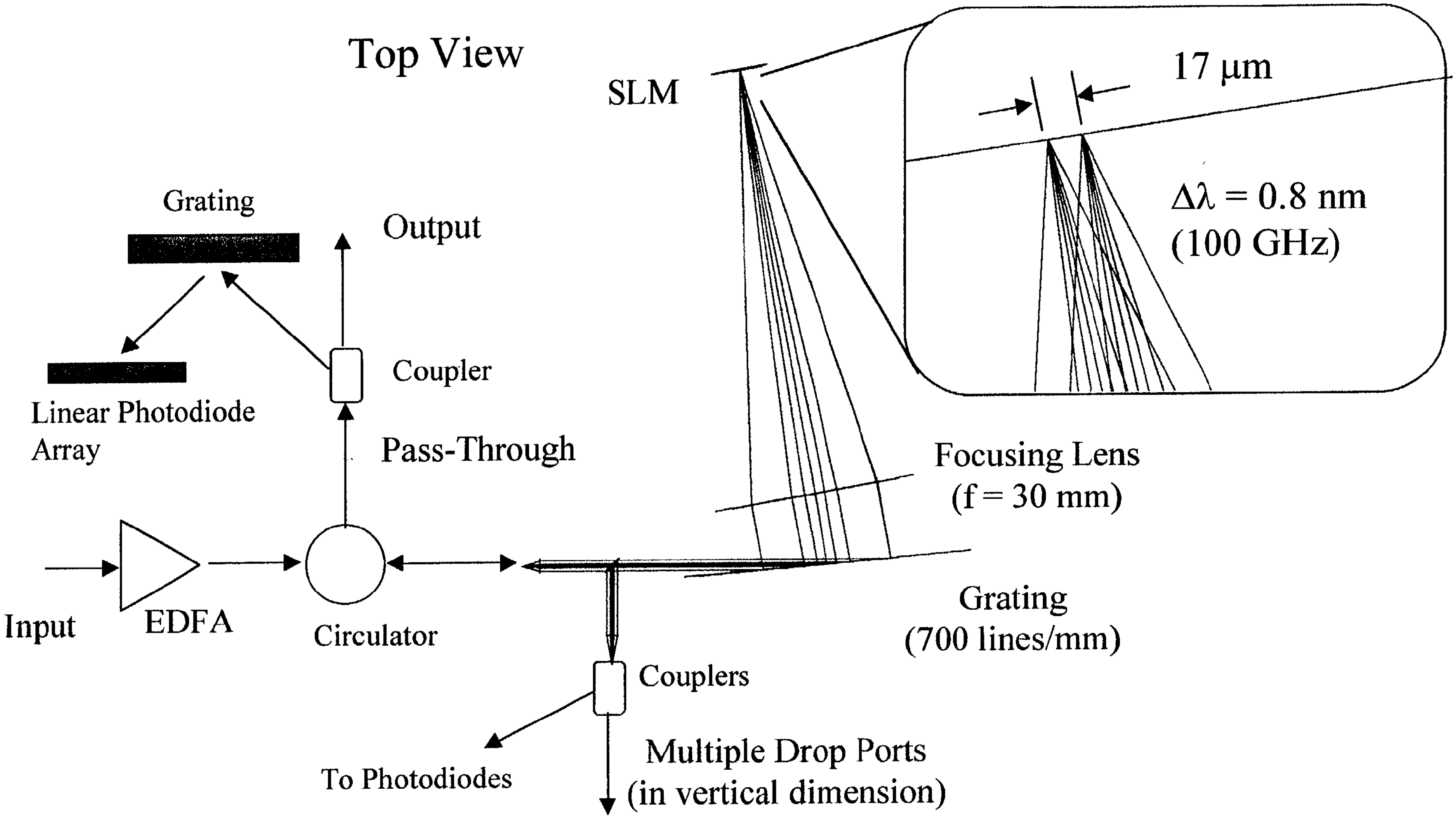
Reconfigurable OADM with Dynamic Equalization

- This invention extends existing the OADM approach (SLM-based) by adding optical spectral feedback on a channel-by-channel basis, and using the feedback signals in a servo system to ensure proper alignment of the system while simultaneously providing by dynamic equalization (or more generally, control over the coupling efficiency of each individual wavelength channel).
- The servo system consists of two parts: (1) linear translation of the SLM chip to ensure alignment between the focused spot array and the mirror array, (2) 1-D tilt of the SLM chip to provide angular control of the reflected beams in the Θx direction, and (3) 1-D tilt of each individual mirror in the SLM in the Θy direction to provide control over the channel-by-channel coupling efficiency.
- Since the coupling efficiency as a function of angular misalignment of the SLM mirrors is Gaussian, the sign ambiguity can be overcome by biasing the coupling to one quadrant in (Θx,Θy) space.
- To overcome loss in the system, an optical amplifier (such as an EDFA) can be added at the input. The spectral variation in the gain can be dynamically equalized by setting the coupling efficiency setpoints of all the channels to be equal.
- The Pass-Through optical feedback signals are obtained by adding an optical coupler at the OADM at the Pass-Through output to pick off a small fraction of the light (e.g., 5%). This light is collimated in free-space, reflected off of a grating similar to that used in the OADM for channel separation, and focused onto a linear photodiode array. In this way, the outgoing optical spectrum is directly measured and compared to the setpoint values to form the error signals for the servo system.
- The Drop optical feedback signals are obtained by using couplers to pick off a small fraction of the light in each drop fiber. Each of these drop signals is then directly detected by a corresponding photodiode for a direct measure of the optical power in each fiber.

Read and Understood 12/28/00 Joseph Davis

Read and Understood 1/3/01 Mark H. Garrett

Capella OADM Design



Note: QWP not shown

Read and Understood 12/28/00

Read and Understood 1/3/01

Appendix D:

Technical Specifications 1/9/2001, Dynamic Optical Add/Drop Multiplexer

Technical Specifications 1/9/2001
Dynamic optical add/drop mux

Channel Spacing	50 Ghz (long haul), 100 Ghz (metro)
Tuning range	40 nm
Tuning speed	<5 ms
Pass channels blocking in tuning	no
Bandwidth at –1.0 dB	**0.2nm**
Bandwidth at –3dB	0.4 nm
Insertion Loss, pass channels	<5 dB
Insertion Loss, drop channels	<7 dB
Adjacent channel rejection	30 dB
Non-adjacent channel rejection	50 dB
PDL	0.2dB
Maximum # of drop channels	16 for long haul, 8 for metro

STANDARDS

NEBS	GR 63-CORE GR-1089
Mechanical & Electrical Safety	UL 1950 EN60825 EN60950
Optical	GR-2918 GR-2979 ITU G.692
EMI/RFI	FCC Part 15, class A EN60825 EN60950

ENVIROMENTAL

Operating Temperature	0 to 50 C
Storage Temperature	-20 to 70 C
Humidity	5 to 90%, non-condensing